A Measurement of Scintillation in CF_4 using GEM Foils and a CsI Photocathode

B.Azmoun, M.Rumore, J.Sinsheimer, N.Smirnov, S.Stoll, C.Woody

***Abstract*—The absolute photon yield of scintillation light produced by highly ionizing particles in pure CF_4 has been measured using a photosensitive GEM detector. The detector consists of two standard GEMs and a CsI coated GEM that acts as a photocathode and is sensitive to the scintillation light produced in CF_4 at 160 nm. The light yield is determined in terms of the number of scintillation photons produced per MeV of energy deposited in the gas by a 5.5 MeV alpha particle using the measured gain and quantum efficiency of the GEM detector, the solid angle acceptance of the detector, and the measured energy loss in the gas. Preliminary measurements show that the yield determined using this method is in very good agreement with other measurements. Scintillation light in CF_4 can potentially play an important role in the performance of the PHENIX Hadron Blind Detector (HBD) as well as other Cherenkov detectors, and its effect on the operation of the HBD at RHIC will be discussed.**

I. Introduction

THE production of scintillation light in highly UV transparent gases such as CF_4 can have an important effect on their use in Cherenkov counters. If the light yield is high, it can produce a significant background that can interfere with the detection of the relatively weak Cherenkov signal, and can cause photon feedback problems in gas detectors. This is the case with the PHENIX Hadron Blind Detector (HBD), which is a windowless Cherenkov counter that is used to identify electrons in relativistic heavy ion collisions and polarized proton interactions at RHIC [1]. This detector utilizes pure CF_4 as both the Cherenkov radiator and as the working gas for GEM detectors that are used to measure charged tracks and detect small numbers of photoelectrons produced by Cherenkov light on a cesium iodide (CsI) photocathode. The HBD detector and its performance during the most recent run at RHIC is described in a separate contribution to this conference [2].

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II. Method

A small GEM detector similar to the ones used in the PHENIX HBD was constructed in order to measure the scintillation light yield in pure CF_4. The detector consists of a stack of three 3x3 cm^2 GEMs, with standard GEMs on the bottom and in the middle, and a gold plated GEM coated with a 200nm film of CsI on the top. Photoelectrons produced on the CsI photocathode are extracted with an electric field and are amplified by the GEM detectors. Figure 1 shows the setup used for the measurement.

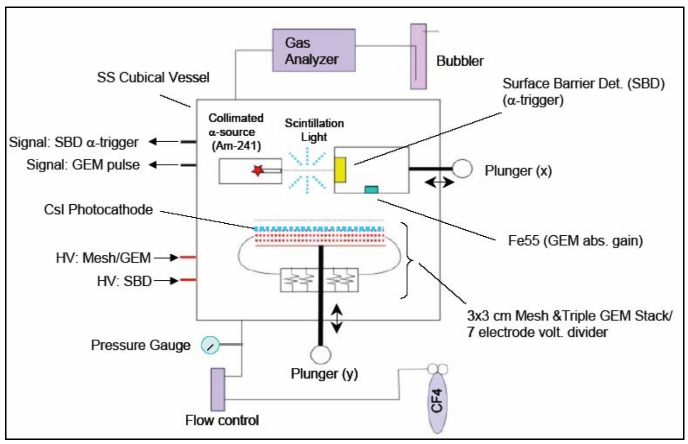

Fig. 1. Setup used to measure the scintillation light produced in CF_4 using a photosensitive GEM detector.

As depicted in the figure above, scintillation light in the gas is produced by alpha particles from an ^{241}Am source, which traverse a well defined gap in CF_4. The residual energy of the alpha is measured after it traverses the gap using a surface barrier detector (SBD). The total energy deposited in the gas is computed by taking the difference between the residual energy and the initial energy of the alpha (5.48 MeV). The SBD is mounted on a plunger so that the path length of the alpha through the gas may be varied. The SBD also acts as a trigger for the GEM detector, thus allowing a simultaneous measure of the photon yield. By differentially comparing the energy loss to the photon yield, dN_γ/dE may be computed.

The GEM detector is mounted on a second plunger which allows the distance between the detector and the alpha particle trajectory to be varied as well. This allows the solid angle seen by the detector to be changed so that the results of simulations of the geometrical acceptance may be compared to real data. Since the number of photons impinging the photocathode is proportional to the photocathode acceptance, the mean number of detected photons at each distance may be converted to an acceptance value through a simple scaling factor. By normalizing real data to the simulation results at a single point, one can see that the overall shapes of the resulting curves overlap very nicely, as depicted in Figure 2 below.

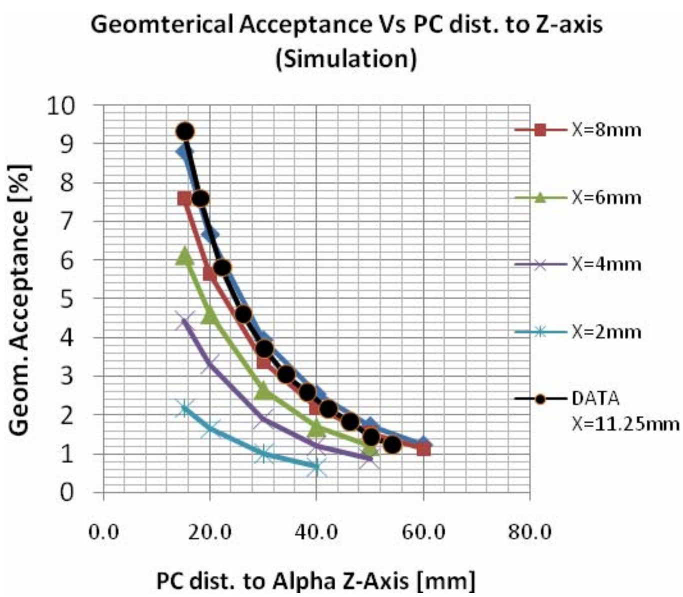

Fig. 2. Results of simulation calculations of the geometrical acceptance of the GEM photocathode, compared to normalized results obtained from actual data. Results presented for different alpha pathlengths.

An ^{55}Fe source is mounted to the back side of the plunger holding the SBD and is used for gain calibration of the GEM detector. The entire assembly is housed inside a stainless steel box that provides a sealed gas volume. Gas is flowed through the detector and the water and oxygen levels are continuously monitored, and are typically below 10ppm each. The temperature and pressure are also monitored in order to correct for any P/T variations in the gas gain.

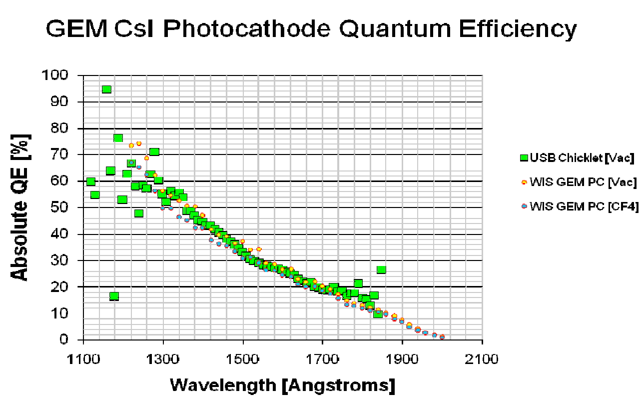

Fig. 3. Quantum efficiency of a typical CsI photocathode.

Figure 3 shows the quantum efficiency of a typical CsI photocathode used in our measurement. Each photocathode was produced using the same facility that is used to produce the photocathodes for the PHENIX HBD detector [1] and had an efficiency of 27.5% at 160 nm.

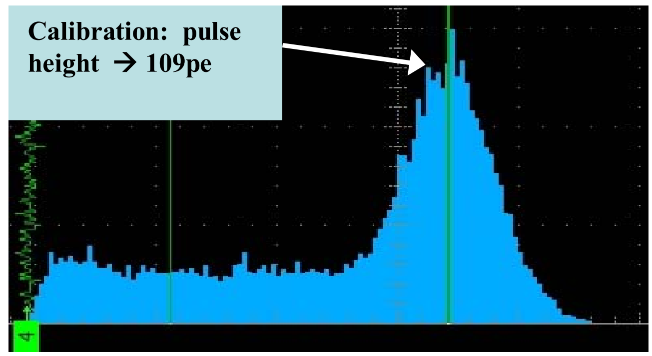

Fig. 4. Pulse height spectrum of the ^{55}Fe source used to calibrate the gain of the GEM. The peak corresponds to 109 primary electrons produced in CF_4.

Figure 4 shows the pulse height spectrum of the ^{55}Fe source used to calibrate the gain of the GEM detector. The peak corresponds to 109 primary electrons in pure CF_4, which was calibrated using an electronic pulser calibration of the preamp and readout electronics. The GEM was operated at a gas gain of 7.9×10^3 and was monitored several times throughout the course of the measurements and found to vary by about 2%.

The photoelectron collection efficiency was maximized by scanning the drift gap field, as depicted in Figure 5a below. The optimum drift field was found to be 0.1kV/cm, which is the field used in all the measurements. The absolute photoelectron collection efficiency was measured as well, in a different set-up, shown in Figure 5b. This measurement was performed at the optimized drift field (0.1kV/cm) and consisted of simultaneously measuring and comparing the signals from the four electrodes (Mesh, GEM-top, GEM-bottom, Pad) of a single, CsI coated GEM detector. In this setup, the GEM was operated in current mode by illuminating the photocathode with a DC lamp with a narrow bandwidth output centered at 160nm. The dV across the GEM was varied from values where the charge transfer efficiency was below 100%, to values that brought the GEM into avalanche mode. As in the scintillation apparatus, the dV across the transfer gap was constrained to equal the dV across the GEM.

The current measured from the GEM (top) electrode in vacuum represents the total available current, and provides an absolute reference. Thus, Figure 5c shows the ratio of the current measured from each electrode in CF_4, divided by the current of the GEM (top) electrode, measured in vacuum at 250V. In addition, the figure shows that the GEM (top) current agrees very nicely at all points with the sum of the currents derived from the mesh, GEM (bot), and pad (CP) electrodes, and confirms that the total current within the circuit is accounted for.

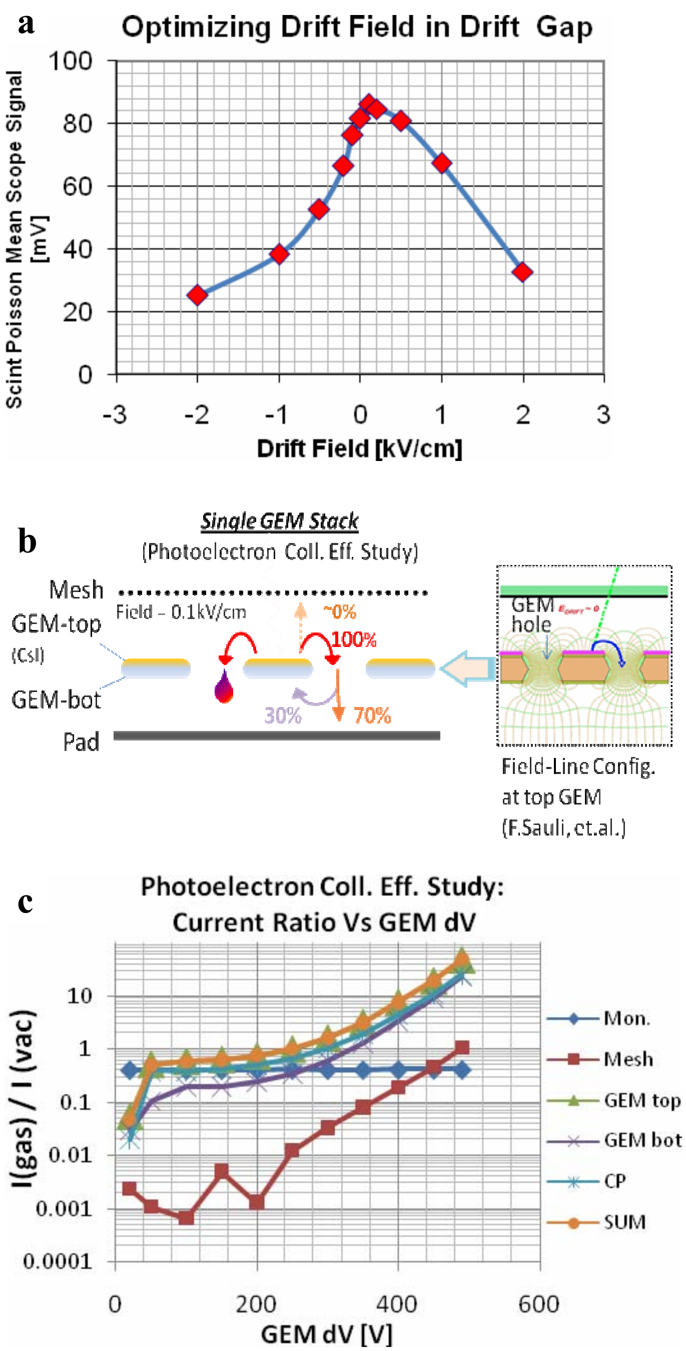

Fig. 5 a) Maximizing GEM drift gap field. b) Sketch of photoelectron collection efficiency test set-up. c) Electrode current in gas normalized to the GEM (top) current in vacuum (measured at dV=250V) Vs GEM dV. At dV~250 the GEM (top) current in gas is equal to the current in vacuum, thus revealing the dV at which unity gain takes place. At dV=250V only 70% of the GEM (top) current is transferred to the pad (CP) in CF4 gas. Additionally, the lamp monitor (Mon.) shows that the lamp output remained stable for the duration of these measurements.

It was found that at a dV equal to ~250V, the photocathode current in gas equaled the value measured in vacuum, which is the point of unity gain. At this point, the primary current from the photocathode was found to split in the ratio of 70% : 30% between the pad and the bottom GEM electrode respectively. The photoelectron collection efficiency was determined at this point since it is assumed that the collection efficiency of primary charge from the ^{55}Fe source is ~100%, and that the gain process for charge derived from both ^{55}Fe and scintillation is the same.

The transmittance of CF_4 was also measured and found to be ~100% over the wavelength region of interest, as depicted below in Figure 6. Thus, there are no losses incurred from photon absorption in the gas.

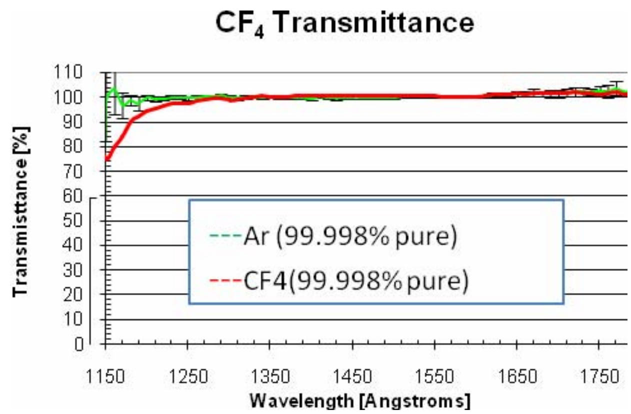

Fig. 6 CF_4 Transmittance is found to be ~100% in the wavelength region of interest.

Lastly, in order to verify that the measured signal is indeed derived from scintillation light, a null test was performed with a gas (P-10) known not to produce scintillation output. No measureable photon signal was observed, as expected.

III. Results

The raw GEM preamplifier pulse height distribution is represented below in Figure 7, and is derived from a Poisson distribution from the incident photons convoluted by a Polya gain distribution from the GEM and a Gaussian distribution due to pedestal noise. Both broadening effects were unfolded from the raw data to derive the pure Poisson distribution due to photon statistics. Taking into account the gain of the triple GEM detector and the remaining experimental parameters, including the mesh and GEM transparency (80%/83% respectively), the mean of the Poisson distribution is converted to a number of scintillation photons emitted into the detector acceptance. The SBD signal is also

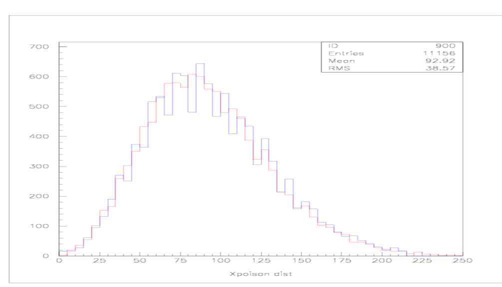

Fig. 7 Parent Poisson distribution convoluted with a Gaussian Pedestal and a Polya distribution(red) ,fit to experimental data (blue).

converted to MeV of residual energy using a conversion factor determined by previously measuring the response of the SBD in vacuum to the same impinging alpha particles. (In vacuum the total initial energy of the alpha is deposited within the SBD, resulting in a signal that exactly corresponds to 5.48MeV.) Finally, the energy deposited in the gas is plotted

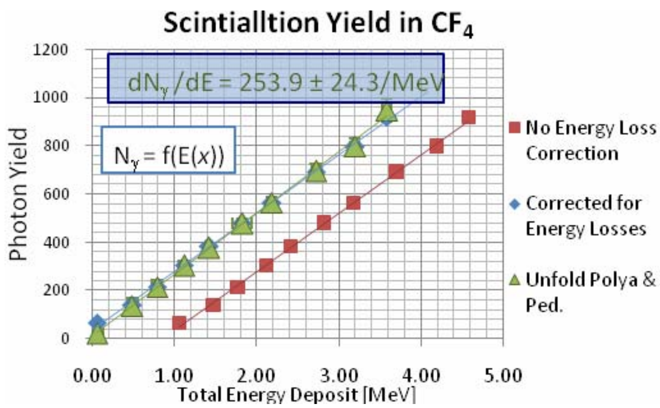

Fig. 8 Scintillation photon yield normalized to 4π solid angle measured as a function of the energy loss of alpha particles in pure CF_4. A fit to the data gives a value of 253.9 photons/MeV.

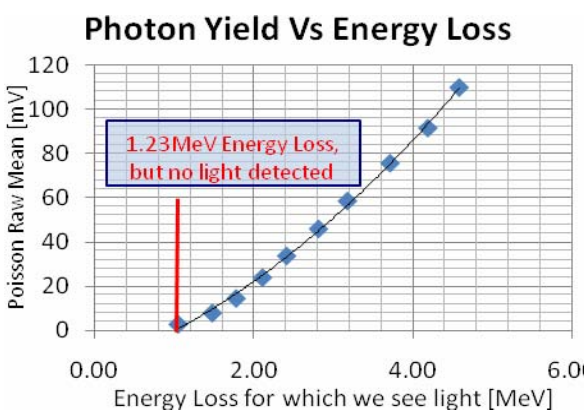

Fig. 9 Energy losses were measured for which there was no detected light, revealing a small portion of the acceptance that was not accounted for by our simulation.

against the number of corresponding scintillation photons, depicted in Figure 8, below. The slope of this plot determines the scintillation photon yield.

The offset in the energy axis is corrected by subtracting off a constant energy deposited in the gas, for which no light is detected. This constant is determined by the plot in Figure 9, and corresponds to a constant offset in the geometrical acceptance, which the simulation did not account for.

Additionally, Figure 10 below shows the range-energy curve for ^{241}Am alphas with an initial energy 5.48 MeV measured in pure CF_4. The results show excellent agreement with the values derived from the literature [3].

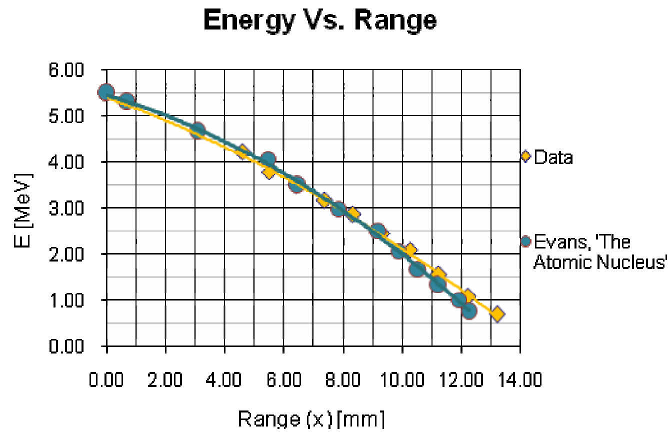

Fig. 10 Range-energy measurement for ^{241}Am alphas measured in CF_4.

IV. Conclusions

Figure 8 gives the absolute scintillation photon yield (normalized to 4π) measured as a function of the energy deposited by alpha particles in CF_4 gas. The values have been corrected for the photocathode CsI quantum efficiency at the photon emission wavelength of 160nm (27%), the transparency of the GEM (83%) and mesh electrode (80%), the solid angle for light collection, and the photoelectron collection efficiency of the GEM detector (~70%). A fit to the data gives a value of 253±24.3 photons per MeV, which is in very good agreement with other measurements obtained using different methods [4].

The HBD detector is sensitive to scintillation light in CF_4 in several ways. One is that the radiator and all of the photocathodes are arranged in a completely open geometry, and any scintillation light which is produced isotropically can easily reach the entire photocathode, causing a potential background for measuring the Cherenkov signal. Secondly, sparks inside the detector produce scintillation light that can also spread over the entire detector and can cause high voltage instabilities in multiple modules. Experience with these effects and in operating the HBD during the 2006-2007 RHIC run have led to the preliminary conclusion that the level of scintillation output observed in CF_4 is low enough to allow successful operation of the detector, even in the very high multiplicity environment of heavy ion collisions. In fact, the scintillation produced in the HBD during heavy ion collisions is used as a source of diffuse light to calibrate the gain of the 12 GEM modules housed within the detector vessel.

V. References

[1] C.L.Woody et.al., "Prototype Tests and Construction of a Hadron Blind Detector for the PHENIX Experiment", Conference Record Proceedings, 2006 IEEE NSS/MIC, Oct 29 - Nov 4 2006, San Diego, CA.

[2] W.Anderson et.al., "Construction, Commissioning and Performance of a Hadron Blind Detector for the PHENIX Experiment at RHIC", contribution to this conference.

[3] "The Atomic Nucleus", R.D.Evans, McGraw-Hill (1955) p 649 (curve in air used to derive range in CF_4.).

[4] A.Pansky et.al., Nucl. Inst. Meth. A354 (1995) 262-269.